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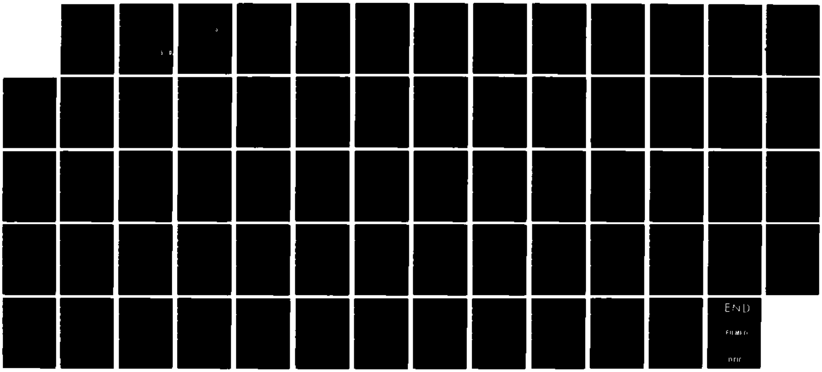

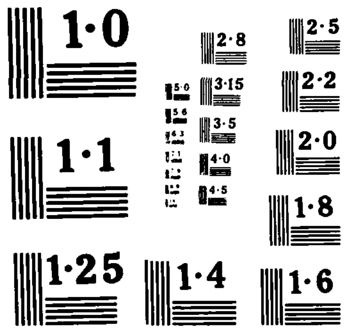
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THESIS

James M. Leonard
Captain, USAF

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USING LOWTRAN-6 COMPUTER CODE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Nuclear Engineering

James M. Leonard, B.S., M.S.S.M.

Captain, USAF

March 1985

Preface

The purpose of this study was to provide the nuclear weapons-effects analyst with accurate transmittance data for burst/target geometries and atmospheric conditions in which thermal radiation effects are of significance, yet without having to run a complex computer code for each specific case under investigation.

The transmittance data were calculated using the LOWTRAN-6 computer code, under varying atmospheric conditions, in the geometry where thermal effects are of primary importance. The results of the calculations are displayed graphically and provide a source of transmittance data representative of many realistic atmospheric and geometric conditions of interest.

I am deeply indebted to my faculty advisor, Dr. Charles J. Bridgman for his patience and understanding. His applied experience guided me away from fruitless endeavors, but allowed me to do my own work. I also wish to thank Mr. Frank W. Jenks, III, AFWAL/WEA for providing me access to the LOWTRAN-6 code.

Finally, I would like to thank my wife, Becky, for her endless reserves of support and concern, without which this thesis would not have been possible.

James M. Leonard

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Abstract

A series of transmittance calculations using LOWTRAN-6, were accomplished to provide the nuclear survivability analyst readily-accessible, accurate information for thermal-effects calculations.

Transmittance values for several realistic sets of atmospheric conditions were obtained using the 1962 U.S. Standard Atmospheric Model and the LOWTRAN Rural, Urban, Maritime, Tropospheric, and Stratospheric aerosol models. Boundary layer (0 - 2 km) transmittance calculations, using the Rural, Urban, and Maritime aerosols, were accomplished for sea-level visibilities of 5, 10, 15, and 23 km. A computer program was developed to weight the LOWTRAN-6 output transmittances according to a 6000 ^{0}K Planckian distribution, simulating a nuclear weapon source. The geometry chosen is for the region where thermal radiation has a significant damage potential to Air Force systems; altitudes from sea-level to 20 kilometers, and ground ranges from 0 - 25 kilometers from weapon ground-zero. The results are displayed in a graphical format, providing the user with accurate nuclear thermal atmospheric transmittance data.

NUCLEAR THERMAL TRANSMITTANCE

IN THE ATMOSPHERE

USING LOWTRAN-6 COMPUTER CODE

I. Introduction

Background

Calculation of the effects of nuclear weapons is essential in predicting the survivability/vulnerability of Air Force systems. One of the primary free-field nuclear effects to be considered is the effect of thermal radiation in the ultraviolet, visible and infrared regions which is emitted within seconds of the explosion. Initial thermal radiation, emanating from the fireball of a nuclear air burst, can vary from roughly 1/3 to 1/2 of the total weapon yield (Ref 2:313). This can represent an enormous amount of energy. The effect of this radiation, as a potential damage/kill mechanism, must be accurately assessed, and combined with other weapon effects (overpressure, gust, prompt radiation etc.) to correctly determine the overall survival probability of the system under study.

When determining the effects of thermal radiation, whether by calculation of thermal fluence (cal/cm^2), or by computation of a system's temperature change by a technique such as the "thin skin" approximate solution of the Fourier heat transfer equation (Ref 1), the nuclear analyst must be able to accurately determine how the atmosphere will

will attenuate the transmitted energy. The primary focal point of this report is the calculation of this attenuation parameter, transmittance, for atmospheric nuclear bursts.

Purpose

The purpose of this analysis is to provide the nuclear weapons-effects analyst with accurate transmittance data for burst/target geometries and atmospheric conditions in which thermal radiation effects are of significance, yet without having to run a complex computer code for each specific case being investigated.

Scope

In this study, nuclear thermal transmittance is calculated for burst/target altitudes from sea-level to 20 km, and for horizontal ground distances (reference ground zero) from 0 to 25 km. Transmittance calculations are made using the Air Force Geophysics Laboratory's computer code, LOWTRAN-6, over the spectral region from 1,000 - 40,000 cm^{-1} (0.25 - 10.0 μm). The LOWTRAN-6 output, transmittance as a function of wavenumber (cm^{-1}), is then weighted according to a Planckian distribution for a blackbody source radiating at 6,000 ^{0}K.

Transmittance data are computed using the 1962 U.S. Standard Atmosphere as the underlying atmospheric model, while using three Boundary Layer (0 - 2 km) aerosol models (Urban, Rural and Maritime), along with the "default"

Tropospheric (2 - 10 km) and Stratospheric (10 - 30 km) aerosol models. For each boundary layer aerosol, transmittance calculations are accomplished at each of four separate sea-level visibility values: 5, 10, 15, and 23 km. In addition, aerosol-free atmospheric profiles are provided for use in extremely clear meteorological conditions.

All transmittance data are presented graphically, parametrically displayed according to the geometry, aerosol models, and visibilities mentioned above. This enables the survivability analyst to obtain fast, reliable values for transmittance, under varying atmospheric conditions, with a minimum of two significant digits of accuracy, well within the precision needed for operational calculations.

Overview

Chapter II of this report contains a brief overview of the theory of nuclear thermal radiation, including a discussion of the thermal source, transmission of thermal radiation, and the interaction of thermal photons with atmospheric constituents. A description of the LOWTRAN-6 code and how it was used is included in Chapter III. Results of the transmittance calculations are presented graphically in Chapter IV, with Chapter V containing conclusions of the study. Empirical-fit equations describing the transmittance-curve data of Chapter IV were obtained using an IMSL least squares curve-fit routine. This information is presented in Appendix A. Included as Appendix B is a user's guide to LOWTRAN-6, for use as an aid when making transmittance calculations. Appendix C contains a listing of the computer program used to weight the LOWTRAN-6 transmittances according to a Planckian distribution.

IV. Results

Transmittance calculations were made using the 1962 U.S. Standard Atmosphere and several representative aerosol models from LOWTRAN-6, at each of four sea-level visibilities. Figure 4 below, contains an illustration of the geometry parameters, as depicted on all of the subsequent transmittance graphs.

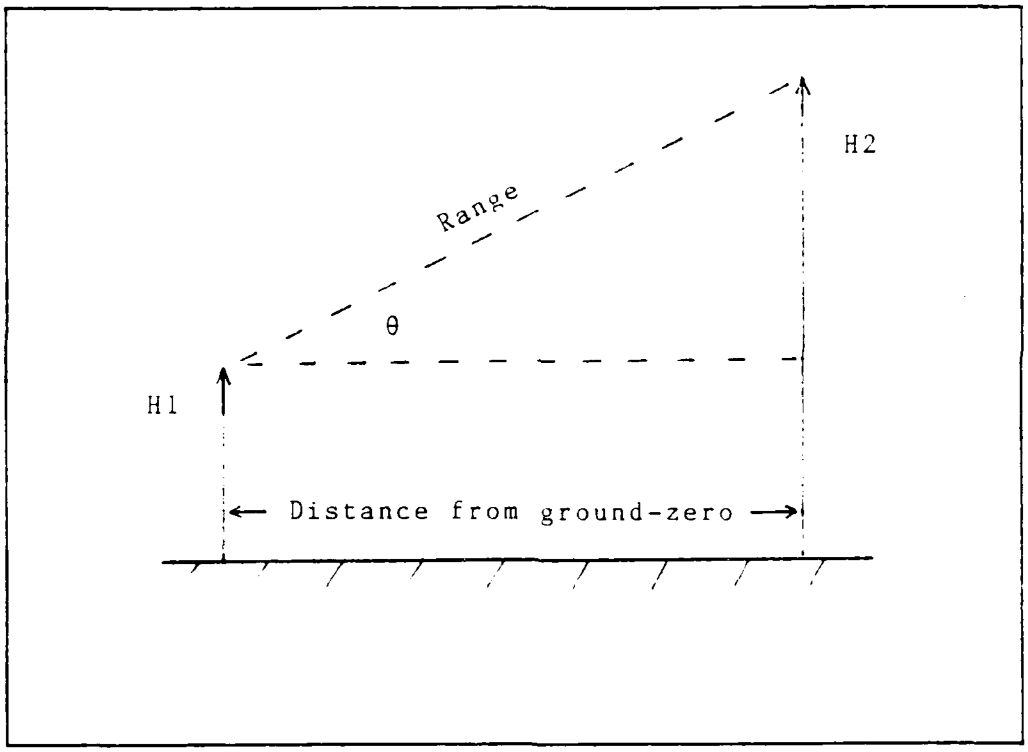

Figure 4. Transmittance Calculation Geometry.

The altitude parameters H1 and H2 represent the heights of the nuclear burst and the receiver/target, or vice versa. For transmittance calculations, H1 and H2 are interchangeable.

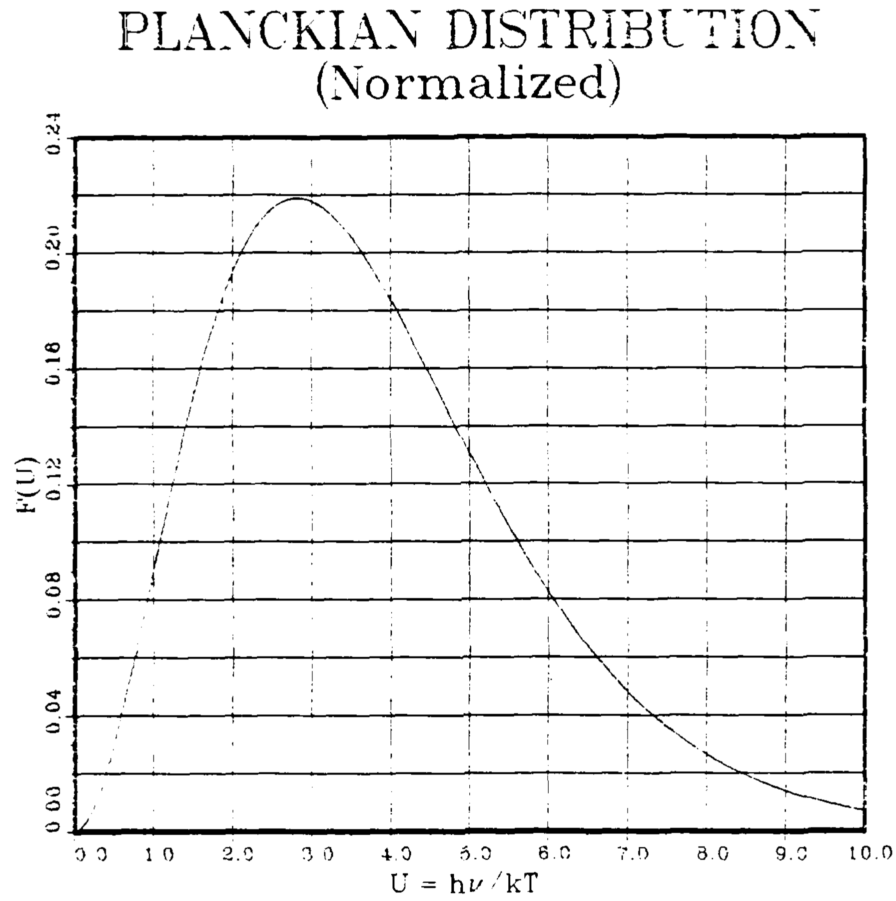

Figure 3. The Normalized Planckian Distribution.

The distribution function, F(U), thus becomes (Ref 6):

$$F(U) = \frac{15}{\pi^4} \left[\frac{U^3}{\exp(U) - 1} \right] \qquad (4)$$

The Planckian integral (area under curve) was computed using Simpson's Rule, with a 1000 mesh space grid (Ref 6:2-3). This method provided accuracies of one part in 10^5.

It is Planckian weighted transmittance data that are needed to compute the thermal radiation effects of nuclear weapons. These data are graphically illustrated in Chapter IV, for the atmosphere, aerosols, and geometries mentioned.

With the range of thermal photon energies from the burst approximated by a 6000 ^{0}K blackbody radiator, and using Planckian tables (Ref 6), the spectral region from 0.25 to 10.0 μm is found to contain more than 98 percent of the total thermal energy emitted from the weapon.

Planckian Weighted Transmittances

The LOWTRAN-6 output provides the user with an average transmittance value for each frequency "band" of the wavenumber width selected (1000 cm^{-1} in this study), over the spectral region chosen (1,000 to 40,000 cm^{-1}). A computer program was written to "weight" these 40 transmittance values according to a 6000 ^{0}K Planckian distribution, so as to approximate a nuclear weapon source. The Planckian distribution is illustrated in Figure 3. This distribution is normalized such that the area under the curve is unity, with the normalized variable, U, given by the expression:

$$U = \frac{h\nu}{kT} \qquad (3)$$

where

h = Planck's constant

ν = photon frequency

k = Boltzmann's constant

T = blackbody temperature

computed (using Eq (1) with $\tau=1$ and $Y_{th}=350$ KT) to fall between 0 and 25 km from the point of detonation. The altitude regime of interest for this study was determined to be for air bursts up to an altitude of 20 km. Since an infinite combination of geometries exists in these altitude and range regimes, transmittance data was calculated only at altitude increments of 5 kilometers, up to and including 20 km. The results of these calculations (Chapter IV) are displayed in a format which allows the transmittance data to be easily interpolated for interim geometries. A low altitude region, nonetheless, was further expanded, with 1 kilometer altitude increments from 0 to 5 km, using the Rural Aerosol Model with a 15 km visibility. This expanded (1 km increment) view of the first 5 kilometers of altitude provides data for possible use in an aircraft base-escape type scenario. In this scenario, the low altitude structure is a primary region of interest.

Spectral Region. LOWTRAN-6 was designed to operate in the region from 350 to 40,000 cm^{-1} (0.25 to 28.5 μm). In this study, the spectral region investigated was from 1,000 to 40,000 cm^{-1} (0.25 to 10.0 μm), in a computation increment of 1000 cm^{-1}. Smaller wavenumber increments (less than 1000 cm^{-1}) were found to have little affect on the ensuing calculations, but resulted in a dramatic increase in computer execution time. The increase in time ranged from 2 to nearly 100 seconds (execution time) on the CDC 6600 CYBER computer system.

Transmittances were also calculated for a perfectly clear or aerosol-free atmosphere, to be used in the appropriate scenario, or as a comparison to illustrate the effects of the different aerosol models on transmittance.

For the aerosol-free environment, it was thought that transmittance might be a smooth function of only one parameter, the "column density" or "mass integral" (Ref 1), as given by:

$$MI = \frac{1}{\sin\theta}\left(\frac{P_1}{g_1} - \frac{P_2}{g_2}\right) \tag{2}$$

where θ is the angle depicted in Figure 4 (page 18), P_1 is the atmospheric pressure at altitude H1, g_1 is the gravitational acceleration at H1, and similarly for P_2 and g_2. This would have eliminated the altitude dependence (geometry) of τ, but transmittance calculations were seen to vary within each atmospheric subdivision, for a constant mass integral.

Geometry. This study was conducted to provide transmittance data for use in calculating the thermal effects of nuclear weapons on selected systems. As such, slant ranges from the burst were confined to the region where thermal fluence would be no less than some minimal value. The minimum chosen was that amount (4 cal/cm^2) which will ignite tinder material such as shredded newspaper (Ref 2:289). The slant ranges of interest, therefore, were visibilities, the user has a wide range of options in identifying the set of parameters that best represents his set of conditions. It should be emphasized, however, that the LOWTRAN-6 parameters are not "exact", but are simply models designed to be as representative of actual atmospheric conditions as known scientific data will allow.

Parameters Selected

The LOWTRAN-6 parameters selected for this study, which had a direct bearing on the transmittance calculations, are highlighted in the following paragraphs.

Atmospheric Model. The 1962 U.S. Standard Atmosphere was chosen as the underlying optical-properties model. This model provides overall atmospheric characteristics suitable for transmittance calculations of a general applications nature, as deemed appropriate in a study of this type.

Aerosol Model. Transmittance values were calculated using each of the three boundary layer aerosol models (Rural, Urban, and Maritime) at each of four sea-level visibilities: 5, 10, 15, and 23 km. This was accomplished to provide a variety of transmittance data representative of several realistic atmospheric conditions. With each of the above boundary layer aerosols, the "default" tropospheric and background stratospheric aerosols were included in their respective atmospheric regions. The option to select stratospheric volcanic ash was not used in these calculations.

types automatically selects the "default" aerosol model for the tropospheric region (2 - 10 km). This model is representative of an extremely clear condition, void of the larger particle sizes present in the boundary layer, due to settling with time.

The stratospheric region (10 - 30 km) is represented by an aerosol model similar to that used in the troposphere, but with the option of selecting conditions which simulate the injection of volcanic ash of varying quantities. Once injected into the stratosphere, such particles are distributed by stratospheric circulation and may take months or years for removal from this region. This aerosol model is also automatically selected when any boundary layer aerosol is chosen.

The upper atmospheric (30 - 100 km) aerosols consist of meteoric dust particles considerably smaller in size (than the other aerosol models), with number densities several orders of magnitude less than found in the lower altitude models.

The user can also select a "clean air" or no aerosol condition in the boundary layer. This may be representative of the conditions encountered after the passage of a weather front. It should be noted that selection of this "no aerosol" model for the boundary layer also selects an aerosol-free troposphere and stratosphere as well.

With the selections available in choosing the underlying atmospheric models, aerosol types, and meteorological

Atmosphere. The models are digitized in 1 kilometer increments from 0 to 25 km, 5 kilometer increments from 25 to 50 km, and at 70 and 100 km directly, as given by McClatchey (Ref 7).

In addition to the six model atmospheres provided, the user has the option of inserting his own atmospheric parameters, if available from radiosonde data or other means. To supplement the basic atmospheric gas profiles, several representative aerosol models are also provided.

Aerosol Models (Ref 4)

The code contains representative aerosol models for each of the four main atmospheric subdivisions: boundary layer, troposphere, stratosphere, and upper atmosphere.

The range of conditions in the boundary layer (0 - 2 km) is represented by three distinct aerosol models (Rural, Urban or Maritime) with sea-level meteorological visibility values from 2 to 50 km. The Rural Aerosol Model is representative of conditions found over continental areas not directly influenced by urban and/or industrial particulate sources. The Urban Aerosol Model is representative of conditions where particulates from combustion and industrial sources are prevalent. The composition and distribution of oceanic aerosols are quite different from continental types. The Maritime Aerosol Model, therefore, is indicative of aerosol particles of sea-salt and sea-spray origin.

Selection of any of the above boundary layer aerosol

III. LOWTRAN-6 Computer Code

Description

LOWTRAN-6 is a Fortran computer code developed by the Air Force Geophysics Laboratory to compute atmospheric transmittance (and radiance) for a given atmospheric path at moderate (20 cm^{-1}) spectral resolution. The code operates on a linear wavenumber scale within the spectral range of 350 to 40,000 cm^{-1} (0.25 to 28.5 μm), with computations in 5 cm^{-1} steps averaged over a 20 cm^{-1} interval (band).

The atmosphere is modeled as a set of 33 concentric, spherical shells originating at sea-level and extending to 100 km. Within this atmospheric shell-model, four primary subdivisions are identified: the Boundary Layer (0 - 2 km), the upper Troposphere (2 - 10 km), the lower Stratosphere (10 - 30 km), and the Upper Atmosphere (30 - 100 km). The program also contains several representative atmospheric constituent and aerosol models, and includes the effects of earth curvature and refractive bending (Ref 5).

Model Atmospheres

LOWTRAN-6 offers the user a choice of six geographic atmospheric models, used as a basis for the computation of atmospheric optical properties (Ref 7:2-7). The user can select either a Tropical Atmosphere, Mid-Latitude Summer or Winter, Subarctic Summer or Winter, or the 1962 U.S. Standard

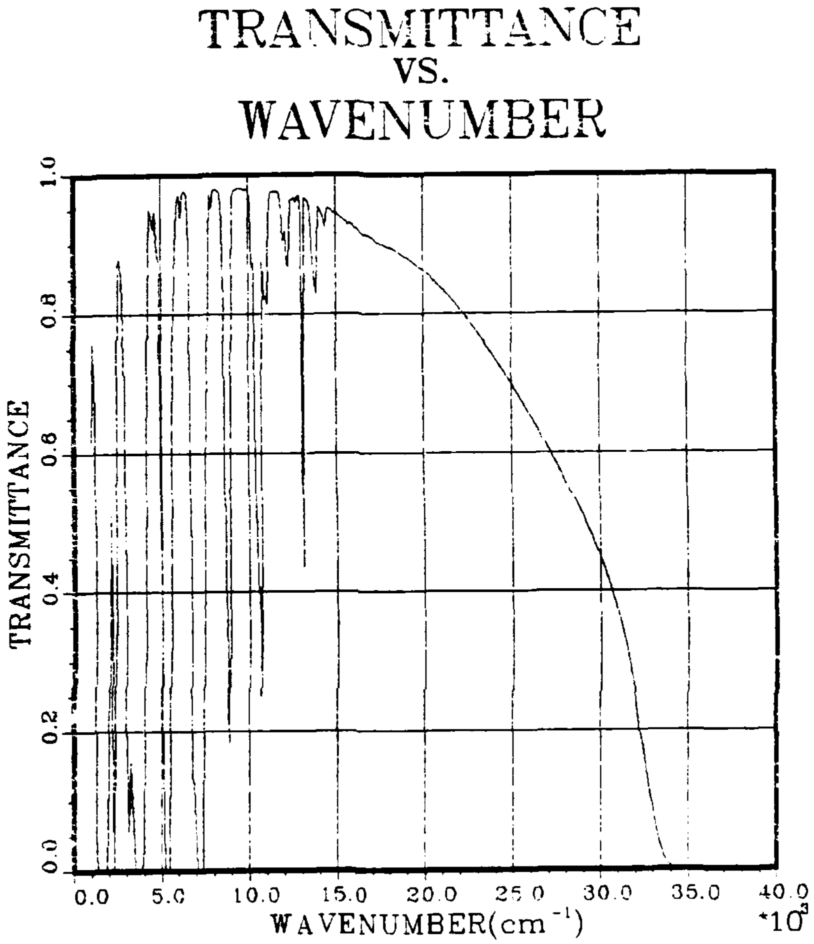

Figure 2. LOWTRAN-6 Computed Transmittance as a Function of Wavenumber, for a Given Geometry and Set of Atmospheric Conditions.

strictly valid only for monochromatic radiation, or at each wavelength for a wide spectral band source such as a nuclear explosion.

It is through the total cross section μ, an extremely sensitive and complex function of the atmospheric gases and particulate matter, that transmittance calculations become cumbersome.

Interaction

Thermal radiation is attenuated as it passes through the atmosphere. The attenuation is due to radiation being absorbed and scattered by the constituent gases and aerosols present along the atmospheric path. The magnitude of the attenuation depends on the associated cross sections for scatter (μ_s) and absorbtion (μ_a), for each atmospheric constituent. As stated above, the total cross section, $\mu = \mu_s + \mu_a$, is a sensitive function of many variables. This is illustrated in Figure 2, on the next page, which depicts how the transmittance can change as a function of photon wavenumber (energy), for a specific geometry and set of atmospheric conditions. The more important absorbers and scatterers influencing the total cross section, and hence transmittance, are: water vapor, carbon monoxide, carbon dioxide, nitric acid, nitrous oxide, nitrogen, oxygen, ozone, methane and aerosols. Atmospheric aerosols are solid or liquid particulate matter such as clouds, rain, fog, dust, smoke, soot, and volcanic ash.

several seconds, depending on the weapon yield (Ref 2:40-41,277).

Thermal radiation from the fireball covers a wide range of frequencies, from the low frequency (long wavelength) infrared region, through the visible, and into the high frequency (short wavelength) ultraviolet region of the electromagnetic spectrum. The radiation received at a distance from a nuclear burst closely resembles that of a perfect radiator, shining at approximately 6000 ^{0}K. As such, a Planckian blackbody distribution is often used to approximate the thermal radiation emission characteristics of a nuclear air burst (Ref 2:305,307).

Transmission

An expression for the transmission of thermal radiation can be derived from first principles. Assuming the nuclear explosion to be a point source with isotropic emission characteristics, and all scattered radiation as removal, the thermal fluence, F(r) is given by (Ref 3:4-5):

$$F(r) = \frac{Y_{th} \exp(-\mu r)}{4\pi r^2} \qquad (1)$$

where Y_{th} is the thermal yield (energy), r is the distance between source and receiver, μ is the total (macroscopic) cross section, and the expression $\exp(-\mu r)$ is the atmospheric transmittance, τ. This expression for τ, however, is

II. Theory of Nuclear Thermal Radiation

Source

The source of thermal radiation from a nuclear explosion is the X-ray fireball. Thermal radiation, from a nuclear air burst, is emitted in two pulses, as shown below in Figure 1.

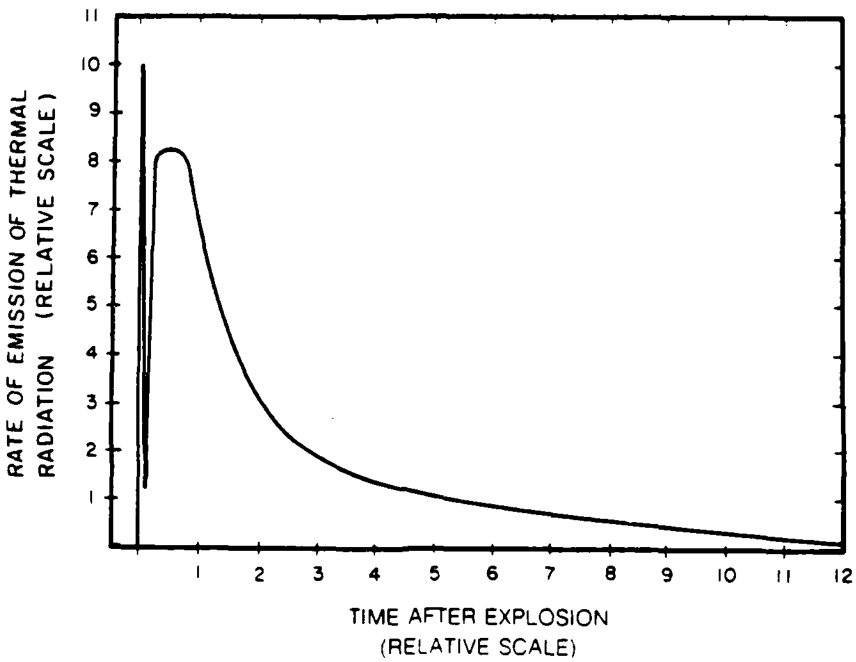

Figure 1. The Two-Pulse Emission of Thermal Radiation from a Nuclear Air Burst (Ref 2:41).

These pulses correspond to the apparent rise and fall of the fireball surface temperature. The first pulse, a fraction of a second in duration, contains only about 1 percent of the total thermal energy, whereas the second pulse contains the remaining 99 percent of the thermal radiance and may last for

Individual points on each transmittance curve represent a LOWTRAN-6 calculation followed by a Planckian weighting of the array of output transmittances.

In each of the first three transmittance graphs (Figures 5 - 7), a separate boundary layer aerosol model was used, at the four distinct visibilities of 5 km (3.1 mi), 10 km (6.2 mi), 15 km (9.3 mi), and 23 km (14.3 mi). Visibilities are inversely proportional to aerosol particulate densities. This range of values gives the survivability analyst a realistic spread of visibilities, resulting in a higher probability of simulating actual conditions. It should be emphasized, as indicated in the figure headings, that one of the altitude parameters (H1 or H2) is to be in the boundary layer for these first three graphs to make any sense. The label "H1=0 km" was chosen, as sea-level (0 km) is the only altitude increment in the geometry chosen for this study (0, 5, 10, 15, and 20 km), which is in the boundary layer.

For example, using the Urban boundary-layer aerosol with a burst height of 10 km, a ground target 20 km from weapon ground-zero, and a visibility of 15 km, the transmittance (Fig 5) is 0.32.

The only difference between Figures 5, 6, and 7 is in the boundary layer aerosol chosen for the transmittance calculations. Figure 5 illustrates transmittance results using the Urban Aerosol Model, where combustion and industrial particulates dominate in the first two kilometers of the atmosphere. Rural, or country-air conditions, are

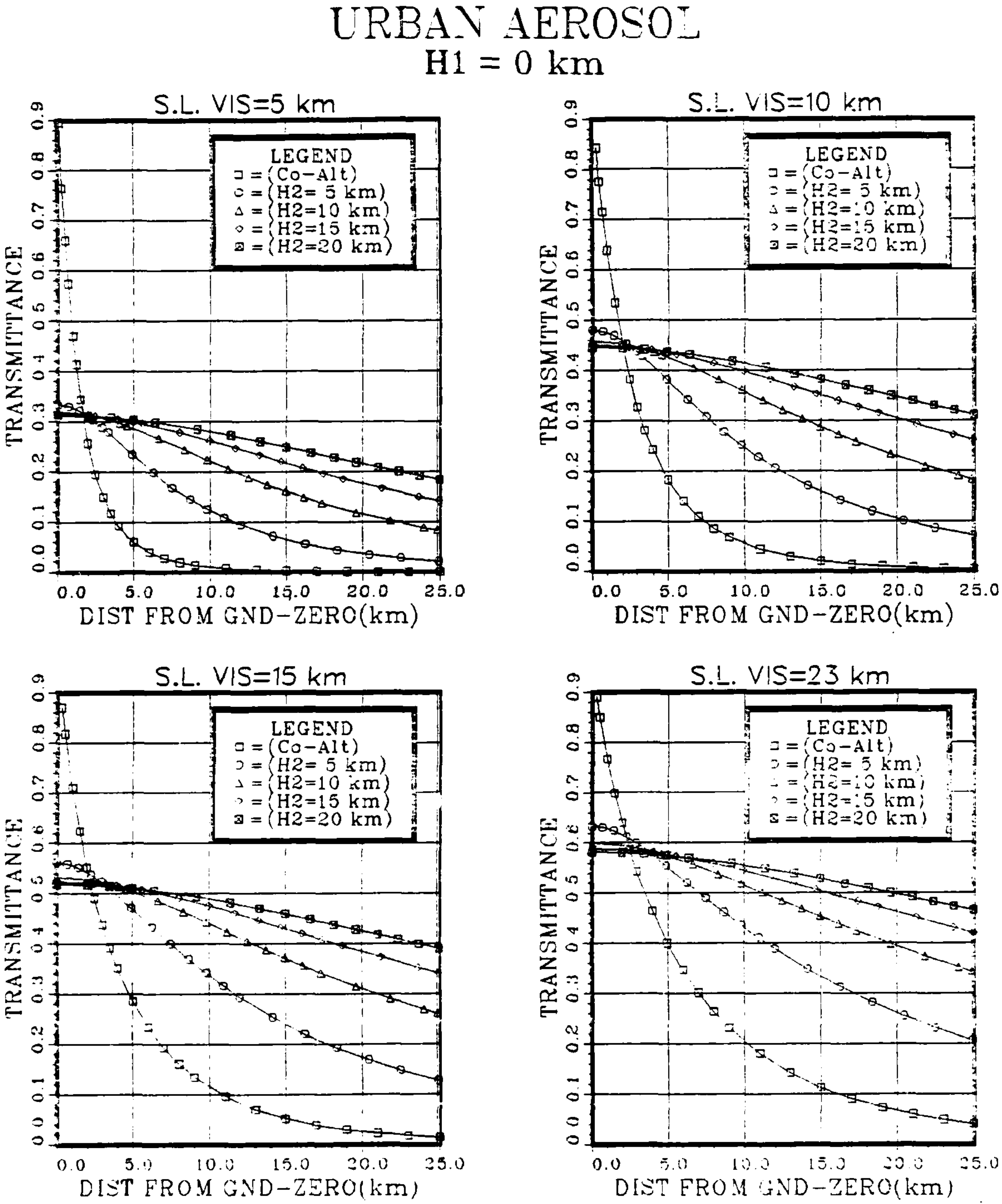

Figure 5. Transmittance Data Using the Urban Aerosol Model in the Boundary Layer.

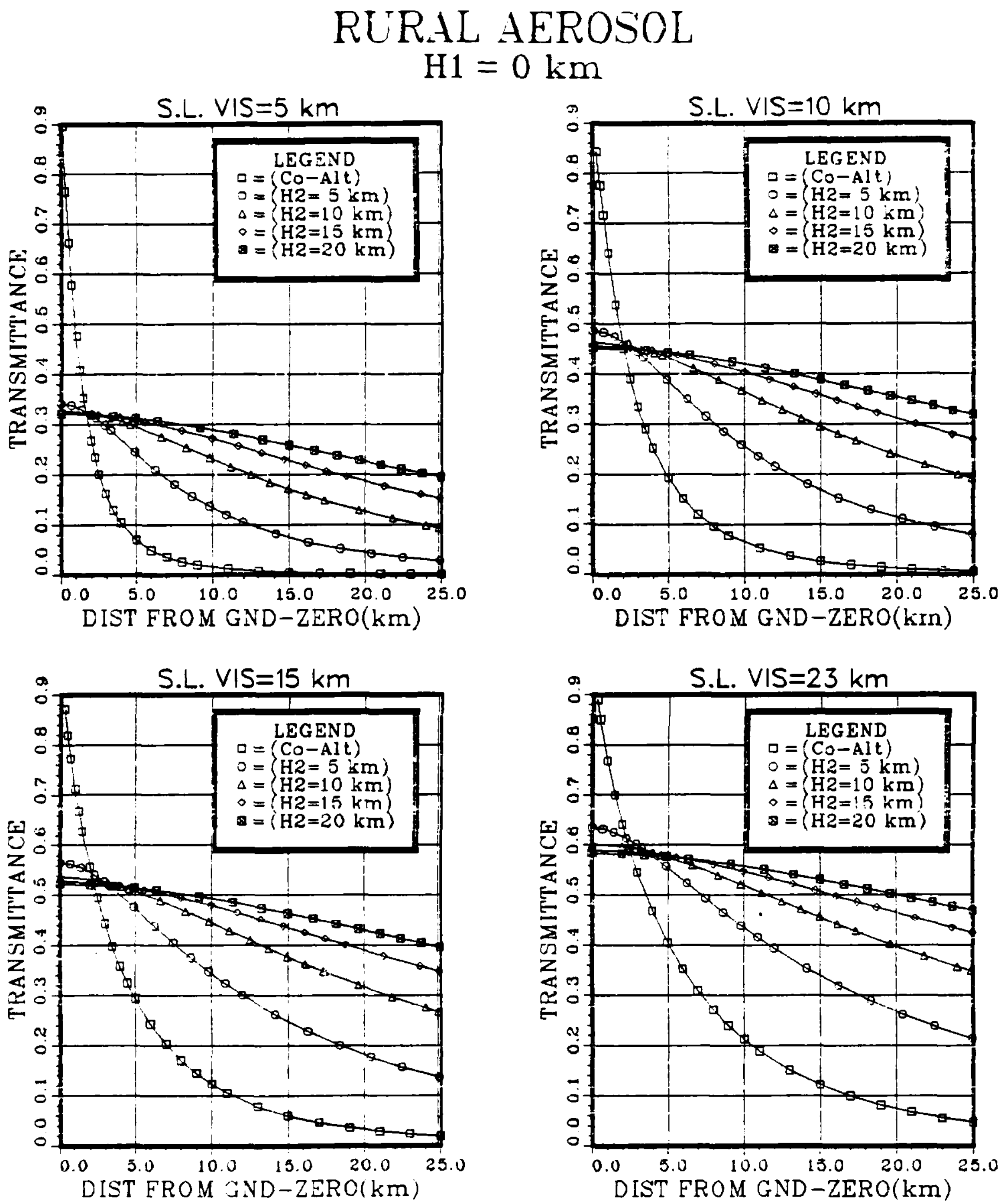

Figure 6. Transmittance Data Using the Rural Aerosol Model in the Boundary Layer.

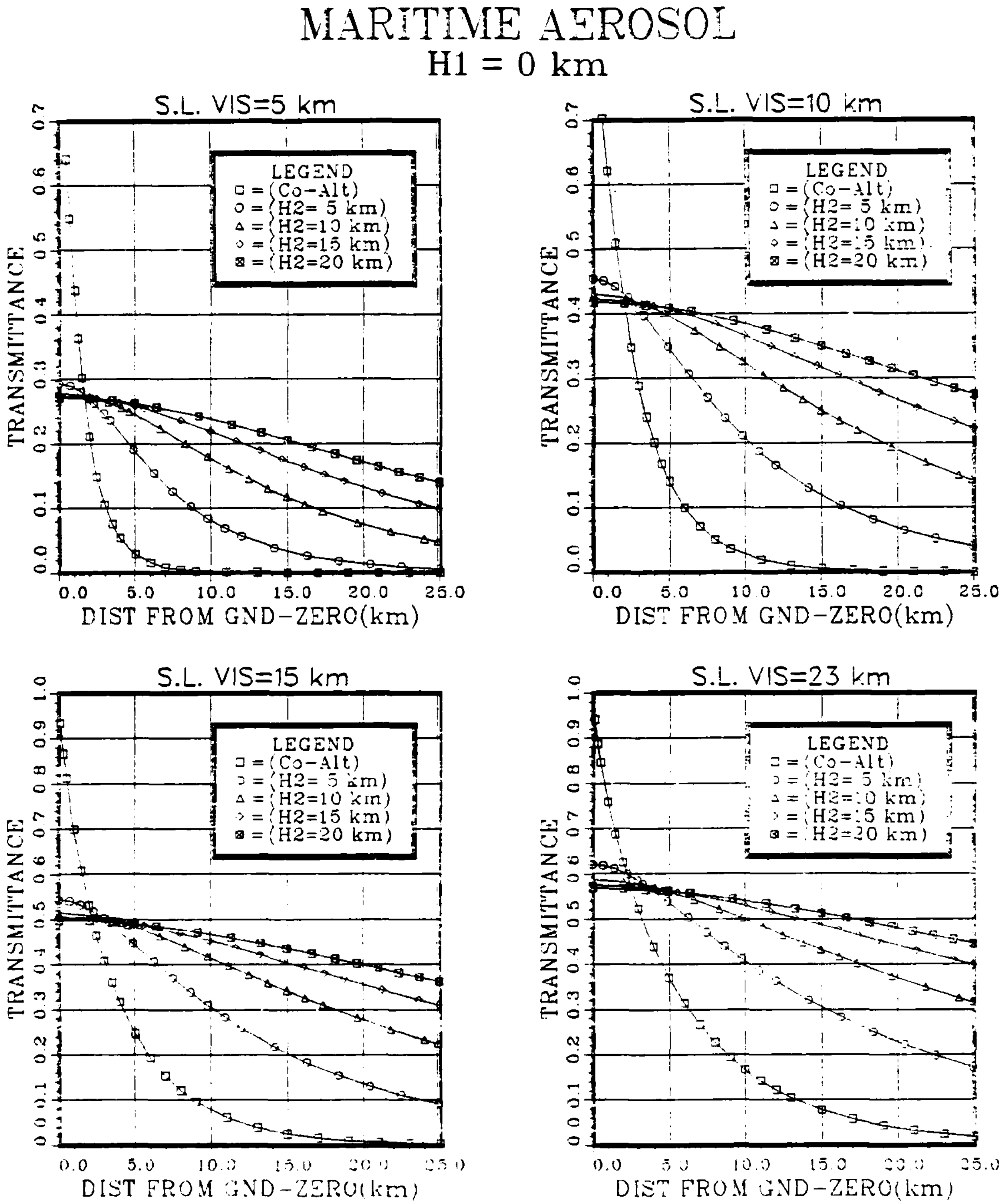

Figure 7. Transmittance Data Using the Maritime Aerosol Model in the Boundary Layer.

illustrated in Figure 6, with the sea-spray and sea-salt boundary layer environment depicted in Figure 7.

These first three graphs are for use when one of the altitude parameters is in the boundary layer. When this is no longer the case, the transmittance values are to be obtained by using Figure 8, Tropospheric/Stratospheric Aerosols. This figure is used when <u>any</u> aerosol model is used in the first two kilometers of atmosphere and <u>neither</u> H1 nor H2 penetrates the boundary layer. The use of any boundary layer aerosol automatically activates the "default" tropospheric (2 - 10 km), and background stratospheric (10 - 30 km) aerosol models in the LOWTRAN code. These regions are indicative of extremely clear conditions, as is indicated in the figure title by a 50 km (31.1 mi) meteorological visibility. It should also be noted that H1 is not a fixed parameter here, as in the previous figures.

Figure 8 can be used in conjunction with Figures 5 - 7 to provide transmittance data for any combination of H1 and H2 within the altitude regime from 0 - 20 km, in 5 km increments.

An "expanded" set of data for the lower altitude (0 - 5 km) structure was calculated, and is displayed as Figures 9 and 9a. These data are based on a specific boundary layer model (Rural), at a specific visibility (15 km), and were included for potential use in a low-altitude, aircraft, base-escape type scenario. The 15 km visibility and a Rural aerosol was selected as representative of conditions at the

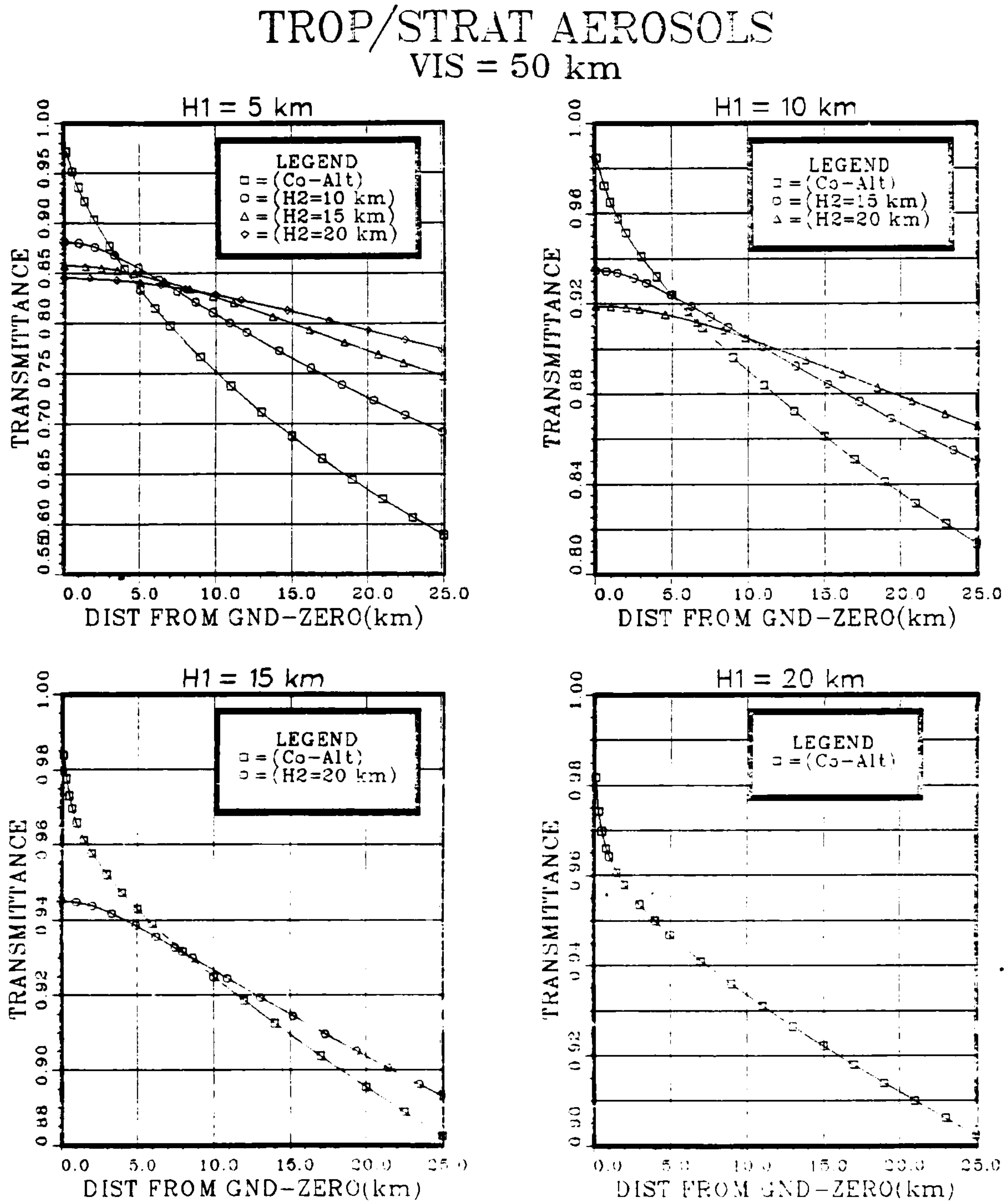

Figure 8. Transmittance Data Using Tropospheric and Stratospheric Aerosols, in the Appropriate Regions.

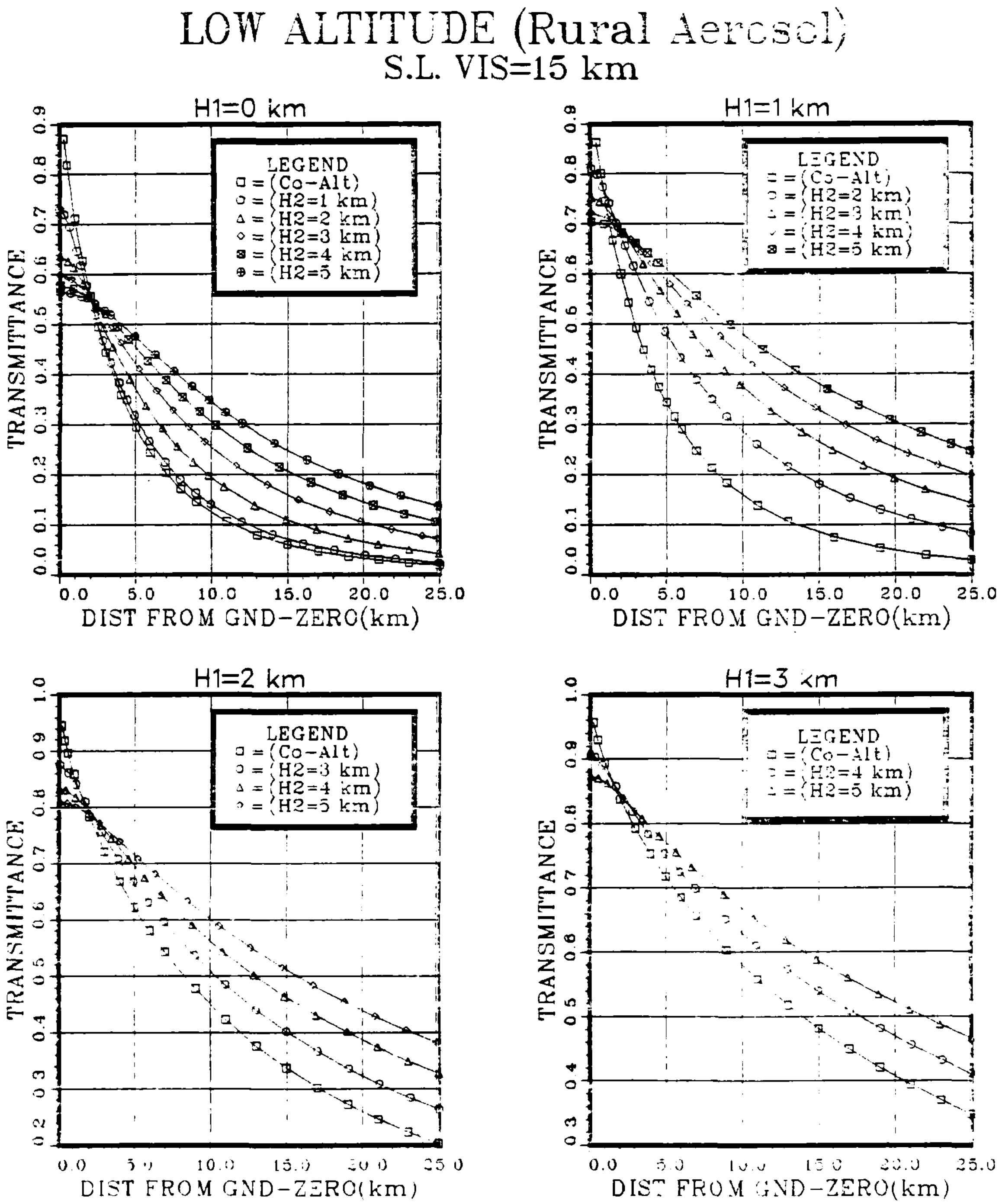

Figure 9. Transmittance Data for the Low Altitude Structure Using Rural Aerosol and 15 km Visibility.

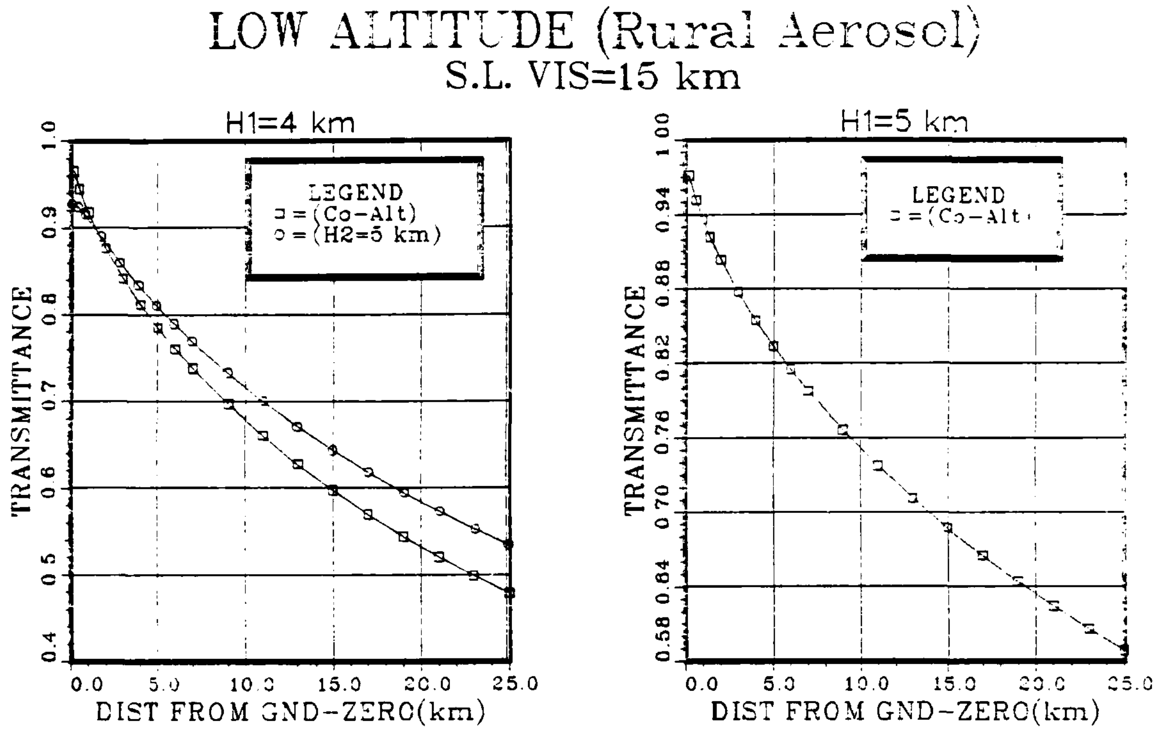

Figure 9a. Transmittance Data for the Low Altitude Structure Using Rural Aerosol and 15 km Visibility.

locations where a nuclear attack in this scenario might likely occur. Since a boundary layer aerosol was used for these calculations, Figure 8, once again, is appropriate for use at altitudes of 5 km and above. It should be noted that Figures 9 and 9a are of a similar format to that of the Tropospheric/Stratospheric aerosol data of Figure 8. Specifically, the aerosol model and visibility is fixed, and the parameter H1 is seen to range (in Figures 9) from 0 to 5 km, in 1 kilometer increments.

A similar set of low altitude transmittance data was calculated for an aerosol-free environment. These data were included for use in very clear or clean-air conditions, as might be seen in the event of strong winds and/or after passage of a weather front. This no-aerosol transmittance data is shown as Figures 10 and 10a. Since no aerosol was used in the first two kilometers of atmosphere, Figure 8 cannot be used for the tropospheric and stratospheric regions, as "default" aerosol data is included in Figure 8. Instead, transmittance calculations in these regions (without aerosols included) is needed, and is depicted in the last transmittance graph, Figure 11.

It is recognized that an infinite number of geometrical combinations are possible when calculating the potential threat that thermal radiation from a nuclear device might pose to a specific system. The utility of the preceding curves, however, is that they can be easily interpolated for interim geometries of interest. Although a constraint of sorts, this far outweighs having to run the time consuming code, and couple the results to a program which will shape the output according to the energy distribution emitted by the thermal source, for each specific set of conditions.

Analytic, curve-fit expressions for all the transmittance curves of the preceeding figures were computed using an International Mathematical & Statistical Libraries (IMSL) curve-fit routine, and are included in Appendix A.

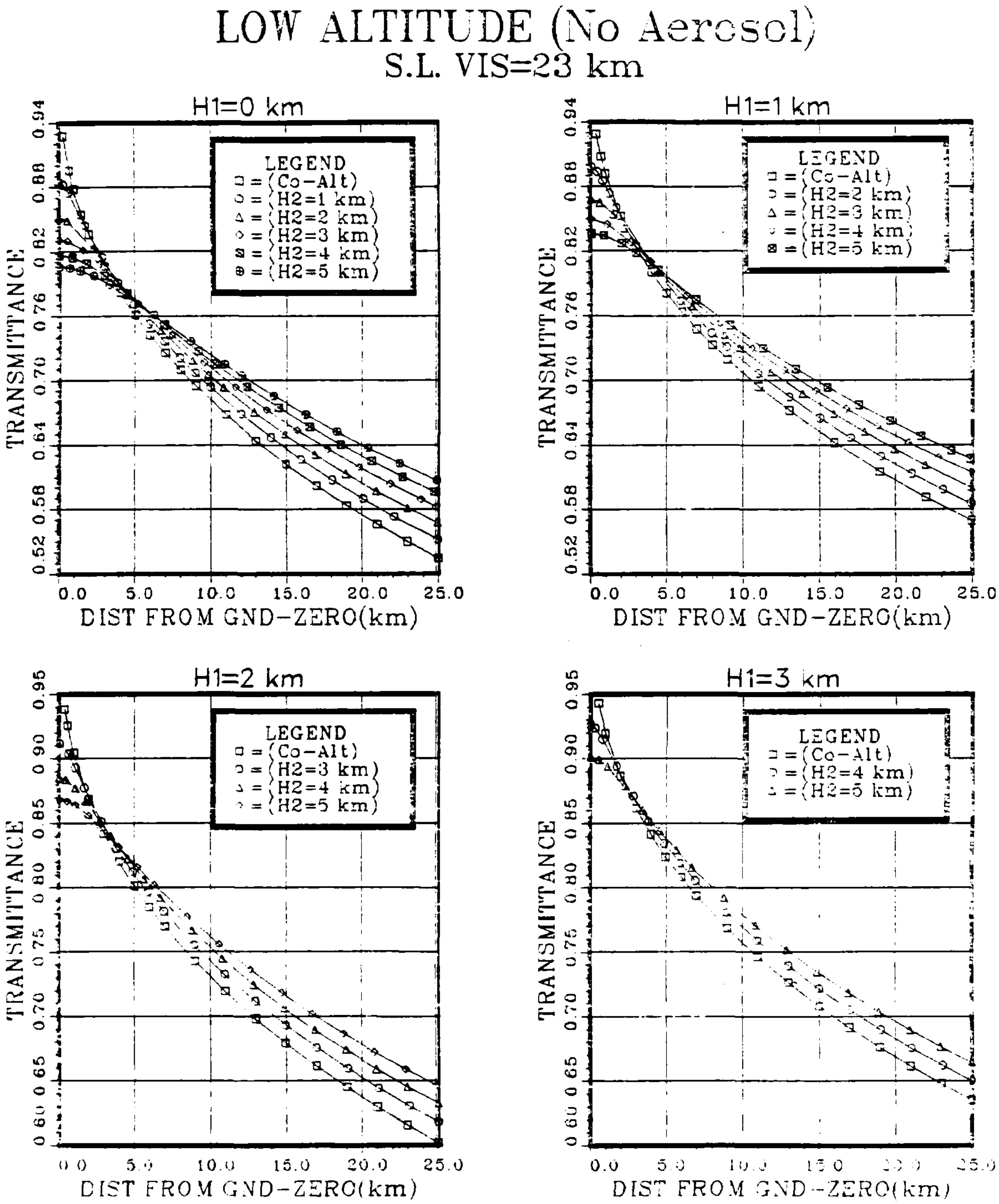

Figure 10. Transmittance Data for the Low Altitude Structure in an Aerosol-Free, 23 km Visibility Environment.

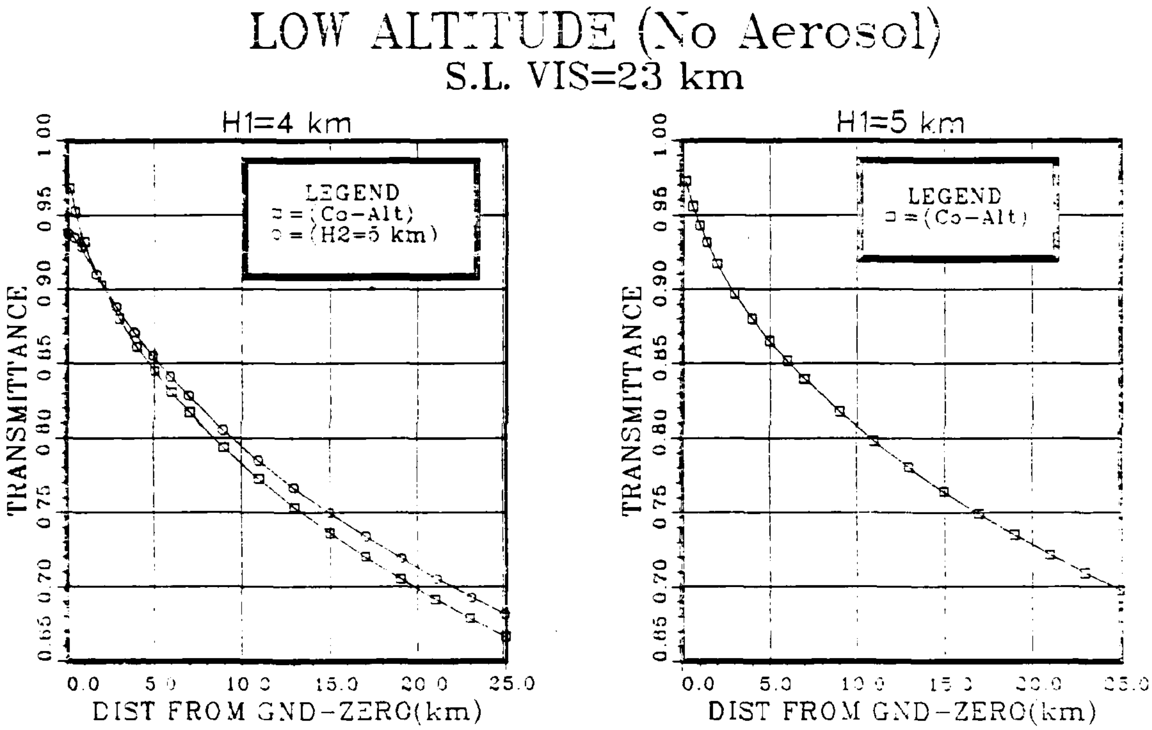

Figure 10a. Transmittance Data for the Low Altitude Structure in an Aerosol-Free, 23 km Visibility Environment.

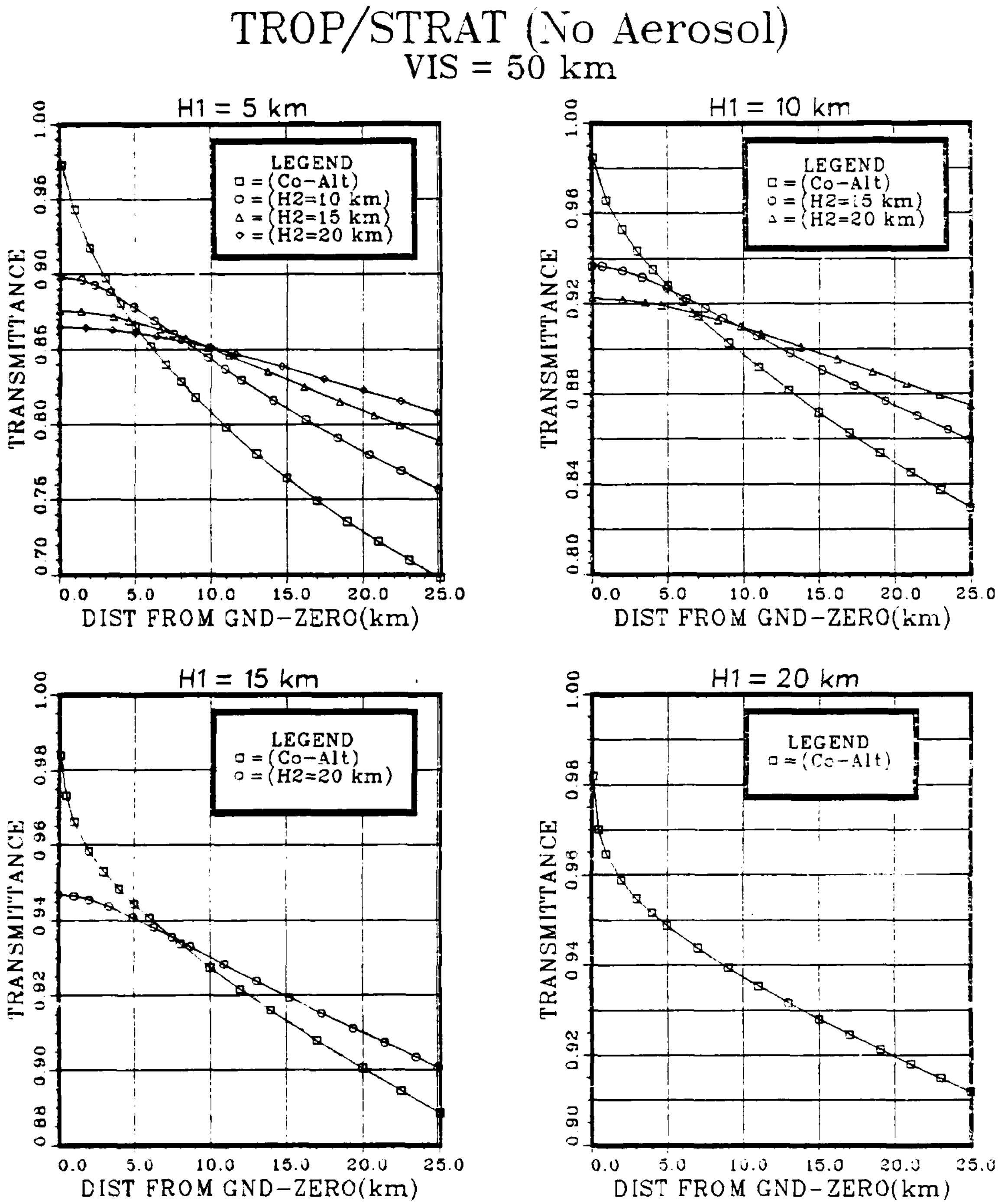

Figure 11. Transmittance Data for the Tropospheric and Stratospheric Regions, in a No-Aerosol Environment.

V. Conclusion

In this study, transmittance data were calculated for a variety of atmospheric and meteorological conditions. These data, based on calculations from the Air Force Geophysics Laboratory's LOWTRAN-6 computer code, and weighted according to a 6000 ^{0}K Planckian distribution, provide the nuclear survivability analyst with appropriate data for assessing nuclear weapon effects on various systems. Specifically, the figures of Chapter IV provide the analyst with the tools necessary for computing the thermal radiation effects of nuclear air bursts, in the geometry where such effects have a high damage potential.

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9 FOG2 (radiation fog) extinction, default VIS = 0.5 km

ISEASN = 0 season determined by the value of MODEL; Spring/Summer for MODEL = 0,1,2,4,6,7 Fall/Winter for MODEL = 3,5

1 Spring/Summer

2 Fall/Winter

IVULCN = 0,1 BACKGROUND STRATOSPHERIC profile and extinction

2 MODERATE VOLCANIC profile and AGED VOLCANIC extinction

3 HIGH VOLCANIC profile and FRESH VOLCANIC extinction

4 HIGH VOLCANIC profile and AGED VOLCANIC extinction

5 MODERATE VOLCANIC profile and FRESH VOLCANIC extinction

If a VIS value is selected, it will override the "default" visibility selected by IHAZE.

For normal operation: ICSTL=ICIR=IVSA=0
WSS=WHH=RAINRT=0

CARD 3 H1,H2,ANGLE,RANGE,BETA,RO,LEN
FORMAT(6F10.3, I5)

H1 = initial altitude (km)
H2 = final altitude (km)
RANGE = path length (km)

For normal operation: ANGLE=BETA=RO=LEN=0

CARD 4 V1,V2,DV
FORMAT(3F10.3)

V1 = initial frequency in wavenumber (cm^{-1})
V2 = final frequency in wavenumber (cm^{-1})
(V2 must be greater then V1)
DV = frequency increment or step size (cm^{-1})

Note: wavenumber = 10,000/microns. DV can take on values that are a multiple of 5. V1 and V2 are reset to the next lowest integer multiple of 5.

CARD 3 H1,H2,ANGLE,RANGE,BETA,RO,LEN
FORMAT(6F10.3, I5)

CARD 4 V1,V2,DV
FORMAT(3F10.3)

CARD 5 IRPT
FORMAT(I5)

Parameter Explanation

CARD 1 MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,TBOUND,SALB
FORMAT(8I5, 2F10.3)

MODEL = 1 selects TROPICAL MODEL ATMOSPHERE
2 selects MIDLATITUDE SUMMER
3 selects MIDLATITUDE WINTER
4 selects SUBARCTIC SUMMER
5 selects SUBARCTIC WINTER
6 selects 1962 U.S. STANDARD ATMOSPHERE
7 if radiosonde data is to be inserted

ITYPE indicates the type of atmospheric path
= 1 for a horizontal (constant-pressure) path
2 for a vertical or slant path between two altitudes
3 for a vertical or slant path to space

For normal operation: IEMSCT=M1=M2=M3=IM=0
NOPRT=TBOUND=SALB=0

CARD 2 IHAZE,ISEASN,IVULCN,ICSTL,ICIR,IVSA,VIS,WSS,WHH,RAINRT
FORMAT(6I5, 4F10.3)

IHAZE = 0 no aerosol attenuation in the calculation
1 RURAL extinction, default VIS = 23 km
2 RURAL extinction, default VIS = 5 km
3 NAVY MARITIME extinction, sets own VIS
4 MARITIME extinction, default VIS = 23 km (LOWTRAN 5 model)
5 URBAN extinction, default VIS = 5 km
6 TROPOSPHERIC extinction, default VIS = 50 km
7 USER-DEFINED extinction, default VIS = 23 km
8 FOG1 (advection fog) extinction, default VIS = 0.2 km

Appendix B

LOWTRAN-6 User's Guide

This appendix is simply a tool for use as a "quick reference" when running LOWTRAN-6 for the purpose of making transmittance calculations. It was not designed nor intended to be used as a replacement for the information/instructions found in Ref 5 of this report.

The set of input instructions to the code are to be created as a file called TAPE4. This input file consists of (usually) five "cards", each in a specific FORTRAN format. The parameters of interest to the transmittance-user, are explained below. Names of the input parameters (variables) are the same as those used in the code, and explained more fully in Ref 5. First, a listing of the cards and their respective formats will be shown, followed by an explanation of those parameters germane to transmittance calculations. Finally, two "typical" examples of the input file TAPE4 will be provided as an illustration of single and multiple calculations.

Card/Format Listing

<u>CARD 1</u> MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,TBOUND,SALB
FORMAT(8I5, 2F10.3)

<u>CARD 2</u> IHAZE,ISEASN,IVULCN,ICSTL,ICIR,IVSA,VIS,WSS,WHH,RAINRT
FORMAT(6I5, 4F10.3)

TABLE A.9

Coefficients for TROP/STRAT (NO Aerosol) Transmittance Data of Figure 11

H1 = 5 km:

H2	C1	C2	C3	C4	C5	C6
5	9.404E-01	-1.975E-02	-2.489E-02	9.818E-03	-3.549E-03	3.833E-04
10	8.983E-01	-7.453E-03	5.661E-03	-5.076E-03	-5.923E-04	1.629E-04
15	8.738E-01	8.324E-03	-1.729E-02	1.316E-02	-5.209E-03	5.429E-04
20	8.590E-01	2.148E-02	-3.008E-02	1.829E-02	-5.338E-03	4.455E-04

H1 = 10 km:

H2	C1	C2	C3	C4	C5	C6
10	9.647E-01	-1.214E-02	-8.245E-03	2.843E-03	-1.355E-03	1.154E-04
15	9.377E-01	-6.817E-03	7.069E-03	-5.286E-03	6.436E-04	-6.489E-05
20	9.178E-01	1.584E-02	-2.141E-02	1.290E-02	-4.023E-03	3.741E-04

H1 = 15 km:

H2	C1	C2	C3	C4	C5	C6
15	9.689E-01	-1.931E-02	9.694E-03	-6.167E-03	1.329E-03	-1.609E-04
20	9.465E-01	-1.598E-03	1.445E-03	-1.816E-03	1.251E-04	-2.473E-05

H1 = 20 km:

H2	C1	C2	C3	C4	C5	C6
20	9.664E-01	-1.415E-02	7.421E-03	-5.008E-03	1.263E-03	-1.578E-04

TABLE A.8

Coefficients for LOW ALTITUDE (NO Aerosol)
Transmittance Data of Figure 10a

H1 = 4 km:

H2	C1	C2	C3	C4	C5	C6
4	9.321E-01	-3.429E-02	-1.231E-02	1.819E-03	-1.339E-03	1.608E-04
5	9.249E-01	-1.730E-02	-1.947E-02	4.010E-03	-1.723E-03	1.889E-04

H1 = 5 km:

H2	C1	C2	C3	C4	C5	C6
5	9.419E-01	-2.440E-02	-1.930E-02	6.683E-03	-2.720E-03	2.998E-04

TABLE A.7

Coefficients for LOW ALTITUDE (NO Aerosol)
Transmittance Data of Figure 10

H1 = 0 km:

H2	C1	C2	C3	C4	C5	C6
0	8.781E-01	-5.189E-02	-1.426E-02	4.458E-03	-2.863E-03	3.755E-04
1	8.624E-01	-1.420E-02	-4.241E-02	1.679E-02	-5.545E-03	6.062E-04
2	8.399E-01	5.504E-03	-3.947E-02	1.149E-02	-3.851E-03	4.305E-04
3	8.264E-01	-5.979E-03	-4.855E-03	-9.214E-03	1.535E-03	-9.534E-05
4	8.167E-01	-1.615E-02	1.447E-02	-1.684E-02	2.770E-03	-1.615E-04
5	8.066E-01	-1.645E-02	1.844E-02	-1.610E-02	2.027E-03	-5.462E-05

H1 = 1 km:

H2	C1	C2	C3	C4	C5	C6
1	8.874E-01	-3.301E-02	-3.313E-02	1.470E-02	-5.177E-03	5.695E-04
2	8.804E-01	-2.499E-02	-2.335E-02	4.806E-03	-1.849E-03	1.889E-04
3	8.603E-01	-8.820E-03	-1.605E-02	-3.229E-03	5.612E-04	-5.148E-05
4	8.458E-01	-8.052E-03	-1.976E-03	-9.939E-03	1.686E-03	-1.003E-04
5	8.401E-01	-2.751E-02	2.775E-02	-2.323E-02	4.356E-03	-3.057E-04

H1 = 2 km:

H2	C1	C2	C3	C4	C5	C6
2	9.068E-01	-4.912E-02	-8.367E-03	3.496E-04	-1.159E-03	1.524E-04
3	8.960E-01	-2.201E-02	-2.371E-02	5.566E-03	-2.099E-03	2.272E-04
4	8.787E-01	-1.002E-02	-1.351E-02	-3.401E-03	4.342E-04	-2.031E-05
5	8.650E-01	-8.412E-03	-4.759E-04	-1.019E-02	1.812E-03	-1.216E-04

H1 = 3 km:

H2	C1	C2	C3	C4	C5	C6
3	9.137E-01	-1.966E-02	-3.716E-02	1.603E-02	-5.178E-03	5.535E-04
4	9.054E-01	4.847E-04	-4.592E-02	1.815E-02	-5.374E-03	5.522E-04
5	8.957E-01	-9.983E-03	-9.569E-03	-5.603E-03	1.168E-03	-1.123E-04

TABLE A.6

Coefficients for LOW ALTITUDE (Rural Aerosol)
Transmittance Data of Figure 9a

H1 = 4 km:

H2	C1	C2	C3	C4	C5	C6
4	9.172E-01	-4.364E-02	-2.475E-02	5.622E-03	-4.116E-03	6.148E-04
5	9.093E-01	-1.767E-02	-3.406E-02	9.715E-03	-4.569E-03	5.823E-04

H1 = 5 km:

H2	C1	C2	C3	C4	C5	C6
5	9.341E-01	-2.811E-02	-2.738E-02	9.520E-03	-4.354E-03	5.175E-04

TABLE A.5

Coefficients for LOW ALTITUDE (Rural Aerosol)
Transmittance Data of Figure 9

H1 = 0 km:

H2	C1	C2	C3	C4	C5	C6
0	7.142E-01	-1.999E-01	-2.109E-02	-4.454E-02	2.696E-02	-3.595E-03
1	6.617E-01	-1.202E-01	-3.654E-02	-5.313E-02	3.010E-02	-3.857E-03
2	6.177E-01	-9.223E-02	5.398E-02	-1.130E-01	4.150E-02	-4.415E-03
3	6.087E-01	-1.340E-01	1.639E-01	-1.581E-01	4.570E-02	-4.159E-03
4	6.101E-01	-1.755E-01	2.216E-01	-1.647E-01	4.052E-02	-3.165E-03
5	5.737E-01	-7.662E-02	9.833E-02	-7.561E-02	1.285E-02	-1.933E-04

H1 = 1 km:

H2	C1	C2	C3	C4	C5	C6
1	7.516E-01	-2.042E-01	1.454E-02	-6.987E-02	3.214E-02	-3.868E-03
2	7.651E-01	-1.014E-01	-2.461E-03	-5.471E-02	1.937E-02	-1.697E-03
3	7.397E-01	-5.881E-02	1.878E-02	-5.596E-02	1.457E-02	-8.698E-04
4	7.142E-01	-2.974E-02	1.395E-02	-3.790E-02	5.871E-03	1.965E-04
5	7.216E-01	-9.269E-02	9.858E-02	-7.085E-02	1.194E-02	-3.374E-04

H1 = 2 km:

H2	C1	C2	C3	C4	C5	C6
2	8.713E-01	-1.307E-01	2.614E-02	-3.567E-02	6.274E-03	-8.025E-06
3	8.467E-01	-4.594E-02	-3.784E-02	5.921E-04	-3.341E-03	8.563E-04
4	8.211E-01	-2.097E-02	-2.143E-02	-8.657E-03	-9.608E-04	5.425E-04
5	8.025E-01	-1.499E-02	-3.003E-03	-1.443E-02	-1.102E-04	4.374E-04

H1 = 3 km:

H2	C1	C2	C3	C4	C5	C6
3	8.898E-01	-4.945E-02	-4.226E-02	1.213E-02	-6.755E-03	1.089E-03
4	8.789E-01	-1.119E-02	-5.799E-02	1.933E-02	-7.829E-03	1.058E-03
5	8.644E-01	-1.335E-02	-1.937E-02	-4.258E-03	-1.128E-03	3.158E-04

TABLE A.4

Coefficients for TROP/STRAT AEROSOL
Transmittance Data of Figure 8

H1 = 5 km:

H2	C1	C2	C3	C4	C5	C6
5	9.341E-01	-2.811E-02	-2.738E-02	9.520E-03	-4.354E-03	5.175E-04
10	8.801E-01	-3.874E-03	-7.331E-04	-1.400E-03	-2.287E-03	3.572E-04
15	8.556E-01	8.824E-03	-1.898E-02	1.468E-02	-5.958E-03	6.088E-04
20	8.399E-01	2.161E-02	-3.106E-02	1.927E-02	-5.750E-03	4.663E-04

H1 = 10 km

H2	C1	C2	C3	C4	C5	C6
10	9.649E-01	-1.582E-02	-5.729E-03	1.442E-03	-1.135E-03	9.448E-05
15	9.346E-01	-3.215E-03	2.027E-03	-2.299E-03	-2.559E-04	2.561E-05
20	9.180E-01	3.540E-03	-7.744E-03	5.854E-03	-2.341E-03	2.103E-04

H1 = 15 km:

H2	C1	C2	C3	C4	C5	C6
15	9.657E-01	-1.041E-02	-1.107E-03	-4.982E-04	-1.079E-04	-2.908E-05
20	9.448E-01	-1.103E-03	5.071E-04	-1.310E-03	-5.588E-05	-1.101E-05

H1 = 20 km:

H2	C1	C2	C3	C4	C5	C6
20	9.642E-01	-8.538E-03	-1.693E-04	-8.572E-04	1.201E-04	-4.892E-05

TABLE A.3

Coefficients for MARITIME AEROSOL
Transmittance Data of Figure 7

VISIBILITY = 5 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	4.287E-01	-2.606E-01	-1.979E-01	2.167E-01	-6.633E-02	6.810E-03
5	3.187E-01	-1.818E-01	2.873E-01	-2.353E-01	7.088E-02	-7.135E-03
10	2.975E-01	-6.127E-02	4.683E-02	-8.257E-03	-9.747E-03	2.269E-03
15	2.159E-01	1.896E-01	-2.467E-01	1.527E-01	-4.730E-02	5.248E-03
20	2.381E-01	1.173E-01	-1.579E-01	9.783E-02	-2.923E-02	2.995E-03

VISIBILITY = 10 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	5.987E-01	-1.463E-01	-2.255E-01	1.020E-01	-7.782E-03	-1.041E-03
5	4.726E-01	-1.375E-01	1.981E-01	-1.528E-01	3.672E-02	-2.567E-03
10	4.178E-01	5.028E-02	-9.777E-02	7.829E-02	-3.325E-02	4.437E-03
15	3.570E-01	2.093E-01	-2.646E-01	1.583E-01	-4.689E-02	4.881E-03
20	3.908E-01	9.487E-02	-1.267E-01	7.693E-02	-2.236E-02	2.098E-03

VISIBILITY = 15 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.041E-01	-2.330E-01	1.604E-02	-8.671E-02	4.535E-02	-6.061E-03
5	5.526E-01	-8.344E-02	1.061E-01	-8.006E-02	1.262E-02	6.892E-05
10	4.982E-01	6.210E-02	-1.098E-01	8.275E-02	-3.273E-02	4.099E-03
15	4.425E-01	1.945E-01	-2.411E-01	1.410E-01	-4.074E-02	4.078E-03
20	4.781E-01	7.175E-02	-9.586E-02	5.755E-02	-1.644E-02	1.425E-03

VISIBILITY = 23 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.764E-01	-2.422E-01	1.054E-01	-1.323E-01	4.725E-02	-5.002E-03
5	6.236E-01	-4.376E-02	4.371E-02	-3.311E-02	-7.870E-04	1.231E-03
10	5.691E-01	6.589E-02	-1.077E-01	7.692E-02	-2.885E-02	3.421E-03
15	5.227E-01	1.642E-01	-2.108E-01	1.167E-01	-3.325E-02	3.226E-03
20	5.534E-01	5.253E-02	-6.994E-02	4.146E-02	-1.166E-02	9.175E-04

TABLE A.2

Coefficients for RURAL AEROSOL
Transmittance Data of Figure 6

VISIBILITY = 5 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	4.739E-01	-2.725E-01	-1.098E-01	1.232E-01	-3.409E-02	3.161E-03
5	3.599E-01	-1.401E-01	2.150E-01	-1.772E-01	5.089E-02	-4.810E-03
10	3.404E-01	-4.044E-02	2.222E-02	4.534E-03	-1.203E-02	2.295E-03
15	2.734E-01	1.519E-01	-2.102E-01	1.296E-01	-4.004E-02	4.373E-03
20	2.934E-01	9.684E-02	-1.305E-01	8.069E-02	-2.406E-02	2.411E-03

VISIBILITY = 10 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	6.298E-01	-1.768E-01	-1.440E-01	5.741E-02	-9.424E-04	-1.089E-03
5	4.996E-01	-1.115E-01	1.576E-01	-1.236E-01	2.884E-02	-1.930E-03
10	4.542E-01	3.512E-02	-7.439E-02	6.166E-02	-2.725E-02	3.655E-03
15	3.969E-01	1.867E-01	-2.354E-01	1.403E-01	-4.147E-02	4.284E-03
20	4.279E-01	8.111E-02	-1.078E-01	6.507E-02	-1.883E-02	1.729E-03

VISIBILITY = 15 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.141E-01	-1.999E-01	-2.083E-02	-4.481E-02	2.705E-02	-3.606E-03
5	5.737E-01	-7.662E-02	9.833E-02	-7.561E-02	1.285E-02	-1.933E-04
10	5.242E-01	5.032E-02	-9.159E-02	6.991E-02	-2.817E-02	3.535E-03
15	4.749E-01	1.664E-01	-2.072E-01	1.217E-01	-3.536E-02	3.536E-03
20	5.026E-01	6.856E-02	-9.081E-02	5.421E-02	-1.542E-02	1.335E-03

VISIBILITY = 23 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.781E-01	-1.992E-01	4.876E-02	-8.423E-02	3.107E-02	-3.242E-03
5	6.378E-01	-4.366E-02	4.653E-02	-3.628E-02	1.453E-03	8.341E-04
10	5.864E-01	5.708E-02	-9.498E-02	6.853E-02	-2.605E-02	3.107E-03
15	5.453E-01	1.414E-01	-1.751E-01	1.019E-01	-2.929E-02	2.846E-03
20	5.707E-01	4.595E-02	-6.140E-02	3.653E-02	-1.033E-02	8.041E-04

TABLE A.1

Coefficients for URBAN AEROSOL
Transmittance Data of Figure 5

VISIBILITY = 5 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	4.654E-01	-2.656E-01	-1.320E-01	1.405E-01	-3.884E-02	3.594E-03
5	3.525E-01	-1.476E-01	2.296E-01	-1.901E-01	5.544E-02	-5.345E-03
10	3.313E-01	-3.867E-02	1.965E-02	6.390E-03	-1.282E-02	2.419E-03
15	2.657E-01	1.612E-01	-2.121E-01	1.320E-01	-4.109E-02	4.517E-03
20	2.836E-01	1.013E-01	-1.366E-01	8.452E-02	-2.520E-02	2.534E-03

VISIBILITY = 10 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	6.253E-01	-1.728E-01	-1.556E-01	6.188E-02	-8.687E-04	-1.228E-03
5	4.948E-01	-1.124E-01	1.588E-01	-1.246E-01	2.887E-02	-1.885E-03
10	4.506E-01	3.116E-02	-7.134E-02	6.104E-02	-2.748E-02	3.715E-03
15	3.896E-01	1.920E-01	-2.407E-01	1.429E-01	-4.208E-02	4.338E-03
20	4.223E-01	8.279E-02	-1.109E-01	6.738E-02	-1.960E-02	1.815E-03

VISIBILITY = 15 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.138E-01	-2.088E-01	-9.459E-03	-5.577E-02	3.123E-02	-4.118E-03
5	5.704E-01	-7.629E-02	9.713E-02	-7.452E-02	1.220E-02	-7.940E-05
10	5.189E-01	5.602E-02	-9.805E-02	7.344E-02	-2.917E-02	3.640E-03
15	4.736E-01	1.607E-01	-2.015E-01	1.191E-01	-3.483E-02	3.489E-03
20	4.985E-01	6.977E-02	-9.172E-02	5.440E-02	-1.540E-02	1.322E-03

VISIBILITY = 23 km; H1=0:

H2	C1	C2	C3	C4	C5	C6
0	7.778E-01	-2.040E-01	5.493E-02	-9.103E-02	3.299E-02	-3.431E-03
5	6.362E-01	-4.460E-02	4.700E-02	-3.614E-02	1.145E-03	8.946E-04
10	5.853E-01	5.404E-02	-9.147E-02	6.664E-02	-2.561E-02	3.063E-03
15	5.441E-01	1.394E-01	-1.735E-01	1.014E-01	-2.923E-02	2.840E-03
20	5.681E-01	4.702E-02	-6[illegible]-02	3.623E-02	-1.012E-02	7.678E-04

visibility data, followed by the 15 km visibility, and then the 23 km visibility data. Also, it is important to note that data for each individual curve is presented in the exact order in which the curves are labeled in the respective "legends" (top to bottom).

Appendix A

Transmittance Curve-fit Data

Analytical expressions for each trasmittance curve were computed using an International Mathematical & Statistical Libraries (IMSL) curve-fit routine called IFLSQ. Each transmittance curve in Figures 5 - 11 is expressed by an equation of the form:

$$Y = C_1 + C_2(\ln x) + C_3(\ln x)^2 + C_4(\ln x)^3 + C_5(\ln x)^4 + C_6(\ln x)^5 \qquad \text{(A-1)}$$

where Y is the Planckian-weighted transmittance, and x is the ground distance (km) between the receiver/target and the burst point. The equations are only valid for x greater than one kilometer and less than or equal to twenty-five kilometers. The accuracy of these "fits" is at least two digits, but generally to three digits of calculated transmittance.

The following tables list the coefficients, C_i, corresponding to those in equation A-1 above. The tables chronologically follow the graphs, Figures 5 - 11, of Chapter IV. As all the figures have multiple plots (usually four per page), it should be noted that the order of presentation of the tabulated coefficient data is from left to right, and top to bottom. For example, for Figure 5, data corresponding to the 5 km visibility is presented first, then the 10 km

CARD 5 IRPT
FORMAT(I5)

The control parameter IRPT causes the program to recycle, so that a series of problems can be run with one submission of TAPE4.

IRPT = 0 to end program
1 to read all data CARDS (1, 2, 3, 4, 5)
2 not used
3 read CARD 3 (geometry card) and CARD 5
4 read CARD 4 (frequency card) and CARD 5

Note: The final IRPT should always be = 0

The following two tables illustrate typical TAPE4 input files. The first, Table B.1, is for a single LOWTRAN-6 transmittance calculation. The second, Table B.2, is using CARD 5 to cause a portion of the program to repeat. In the second examp`.., transmittance is to be computed for several different geometries, all other parameters remaining constant.

TABLE B.1

TAPE4 for a Single LOWTRAN-6 Calculation

```
    6    2    0    0    0    0    0    0     0.000     0.000
    5    0    0    0    0    0     8.000     0.000     0.000     0.000
     1.500    12.000     0.000    17.000     0.000     0.000    0
  1000.000 40000.000  1000.000
    0
```

The preceding table illustrates a LOWTRAN-6 run using the 1962 U.S. Standard Atmosphere, with the URBAN aerosol model and a sea-level visibility of 8 km. The transmittance is to be computed over the optical path from an altitude of 1.5 km to an altitude of 12 km, with the path length equal to 17 km. The spectral region is from 1,000 - 40,000 cm^{-1} with a calculational increment of 1,000 cm^{-1}.

The following table is identical to Table B.1, except the code is to be repeated for an additional five geometries. Note carefully the use of the parameter IRPT.

TABLE B.2

TAPE4 for Multiple LOWTRAN-6 Calculations

```
  6    2    0    0    0    0    0    0     0.000     0.000
  5    0    0    0    0    0     8.000     0.000     0.000     0.000
   1.500    12.000     0.000    17.000     0.000     0.000    0
1000.000 40000.000  1000.000
  3
   4.000     5.500     0.000     6.000     0.000     0.000    0
  3
   1.000    15.000     0.000    16.500     0.000     0.000    0
  3
   0.000    20.000     0.000    22.000     0.000     0.000    0
  3
   9.000     3.000     0.000    11.000     0.000     0.000    0
  3
  13.000     2.000     0.000    18.000     0.000     0.000    0
  0
```

Appendix C

Computer Program Listing (Planckian Weighting)

The following pages contain a listing of the computer program (BBODY) used to weight the output transmittances of LOWTRAN-6 according to a Planckian blackbody distribution at 6000 ^{0}K.

```
      PROGRAM BBODY

C-----------------------------------------------------------------C
C      THIS PROGRAM READS THE FILE (TAPE7) CONTAINING THE OUTPUT    C
C      OF LOWTRAN-6.  THE TOTAL AVERAGE TRANSMITTANCE (AT EACH      C
C      WAVENUMBER INCREMENT) IS THEN WEIGHTED ACCORDING TO A        C
C      PLANCKIAN DISTRIBUTION, FOR A GIVEN BLACKBODY TEMPERATURE.   C
C      THE AVERAGE TRANSMITTANCE FOR THE WEIGHTED SPECTRUM THEN     C
C      COMPUTED.                                                    C
C-----------------------------------------------------------------C

      REAL TBOUND,SALB,VIS,WSS,WHH,RAINRT,CTHIK,CALT,ZCVSA,ZTVSA
     +     ZINVSA,H1,H2,ANGLE,RANGE,BETA,RO,PARM1,PARM2,PARM3,PARM4
     +     TIME,PSIPO,ANGLEM,G,V1,V2,DV,TRAIN,TCRRIS,DV2
     +     HOLD,DIFF,BBTEMP,FR,VLEFT,VRIGHT
     +     THETA,GDIST,VIS1ST,U,H,C,K,PLSUM,ULEFT,URIGHT
     +     TAUSUM,LINAVG,WGTSUM,VHZ

      INTEGER I,M,MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,IHAZE,ISEASN
     +        IVULCN,ICLTL,ICIR,IVSA,ISEED,ML,LEN,IPARM,IPH,IDAY
     +        ISOURC,IRPT,INC,NROWS

      REAL T(2000,13), P(2000,5), F(2000)

      CHARACTER*72 NAME,HEADR
      CHARACTER*75 TITLE1,TITLE2
      CHARACTER*18 ATMOS,GEOM1,GEOM2,GEOM3,GEOM4,GEOM5,LINES
      CHARACTER*40 DUST
      CHARACTER*10 PATH

C-----------------------------------------------------------------C
C                    READ HEADER DATA ON TAPE7                      C
C-----------------------------------------------------------------C

      OPEN(UNIT=7, FILE='TAPE7')
      REWIND 7

      READ(7,905)MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,TBOUND,SALB
      READ(7,910)IHAZE,ISEASN,IVULCN,ICSTL,ICIR,IVSA,VIS,WSS,WHH,RAINRT
      READ(7,915)CTHIK,CALT,ISEED
      READ(7,920)ZCVSA,ZTVSA,ZINVSA
      READ(7,925)ML,NAME
      READ(7,930)H1,H2,ANGLE,RANGE,BETA,RO,LEN
      READ(7,935)IPARM,IPH,IDAY,ISOURC
      READ(7,940)PARM1,PARM2,PARM3,PARM4,TIME,PSIPO,ANGLEM,G
      READ(7,945)V1,V2,DV
      READ(7,950)IRPT
      READ(7,955)TRAIN,TCRRIS

      IF (LEN .EQ. 0) THEN
         PATH='SHORT'
```

```
   ELSE
    PATH='LONG'
   ENDIF

 BBTEMP=6000.
 VIS1ST=VIS
 TITLE1='          LOWTRAN-6 COMPUTED DATA'
 TITLE2='          PLANCKIAN WEIGHTED TRANSMITTANCES'
 HEADR='ATMOS MODEL   =   1962  U.S. STD ATMOSPHERE'
 ATMOS='AEROSOL MODEL ='
 GEOM1='H1   (TARGET) ='
 GEOM2='H2   (BOMB)   ='
 GEOM3='PATH LENGTH   ='
 GEOM4='GROUND DIST   ='
 GEOM5='THETA         ='
 LINES='NO. OF LINES  ='
 H=6.626176E-34
 C=2.99792454E8
 K=1.380662E-23
 THETA=90-ANGLE
 GDIST=SQRT(RANGE**2 - (H2-H1)**2)

 IF (ITYPE .EQ. 1) THEN
    PATH='HOROZONTAL'
    THETA=0.
    GDIST=RANGE
   ENDIF

 IF (IHAZE .EQ. 0) THEN
    DUST='NO AEROSOL INCLUDED:  VIS ='
    VIS=23.
 ELSEIF (IHAZE .EQ. 1) THEN
    DUST='RURAL:  VIS ='
    VIS=23.
 ELSEIF (IHAZE .EQ. 2) THEN
    DUST='RURAL:  VIS ='
    VIS=5.
 ELSEIF (IHAZE .EQ. 3) THEN
    DIST='NAVY MARITIME: VIS ='
    VIS=999.
 ELSEIF (IHAZE .EQ. 4) THEN
    DUST='MARITIME:  VIS='
    VIS=23.
 ELSEIF (IHAZE .EQ. 5) THEN
    DUST='URBAN:  VIS ='
    VIS=5.
 ELSEIF (IHAZE .EQ. 6) THEN
    DUST='TROPOSPHERIC:  VIS ='
    VIS=50.
 ELSEIF (IHAZE .EQ. 7) THEN
    DUST='USER-DEFINED:  VIS ='
    VIS=23.
```

```
      ELSEIF (IHAZE .EQ. 8) THEN
         DUST='FOG1(ADVECTION FOG):  VIS ='
         VIS=0.2

      ELSEIF (IHAZE .EQ. 9) THEN
         DUST='FOG2(RADIATION FOG):  VIS ='
         VIS=0.5
      ENDIF

      IF (VIS1ST .NE. 0) THEN
         VIS=VIS1ST
        ENDIF

      DIFF=V2-V1
      IF (INT(DIFF/DV)-DIFF/DV .EQ. 0) THEN
         INC=1
        ELSE
         INC=2
        ENDIF
      NROWS=INT(DIFF/DV) + INC
      DV2=DV/2.

C-------------------------------------------------------------------C
C               READ TRANSMITTANCE DATA FROM TAPE7                  C
C-------------------------------------------------------------------C

COMMENT:    THE FOLLOWING LINE READS THE TAPE7 TRANSMITTANCE DATA
COMMENT:    INTO A TWO-DIMENSIONAL ARRAY ("T"), WHICH IS NROWS X 13.

      READ(7,900)((T(I,J),J=1,13),I=1,NROWS)
      REWIND 7

      TAUSUM=0.
      PLSUM=0.
      DO 300 I=1,NROWS
         VLEFT=T(I,1)-DV2
         VLEFT=VLEFT*2.99792458E10
         ULEFT=(H*VLEFT)/(K*BBTEMP)

         VRIGHT=T(I,1)+DV2
         VRIGHT=VRIGHT*2.99792458E10
         URIGHT=(H*VRIGHT)/(K*BBTEMP)

         CALL PLFRAC(ULEFT,URIGHT,FR)
         F(I)=FR
         PLSUM=PLSUM+F(I)
         TAUSUM=TAUSUM+T(I,3)
300   CONTINUE

      LINAVG=TAUSUM/NROWS

      WGTSUM=0.
```

```
      DO 500 I=1,NROWS
         P(I,1)=T(I,1)
         P(I,2)=T(I,2)
         HOLD=F(I)*T(I,3)
         P(I,3)=HOLD
         P(I,4)=F(I)
         VHZ=T(I,1)*2.99792458E10
         U=(H*VHZ)/(K*BBTEMP)
         P(I,5)=U
         WGTSUM=WGTSUM+P(I,3)
500   CONTINUE

      OPEN(UNIT=8, FILE='WGT')
      REWIND 8

      WRITE(8,995)
      WRITE(8,959)HEADR
      WRITE(8,990)ATMOS,DUST,VIS
      WRITE(8,992)PATH
      WRITE(8,980)GEOM1,H1
      WRITE(8,980)GEOM2,H2
      WRITE(8,980)GEOM3,RANGE
      WRITE(8,980)GEOM4,GDIST
      WRITE(8,980)GEOM5,THETA
      WRITE(8,1000)LINES,NROWS

      WRITE(8,961)TITLE1
      WRITE(8,970)
      WRITE(8,971)
      WRITE(8,900)((T(I,J),J=1,13),I=1,NROWS)
      WRITE(8,998)LINAVG

      WRITE(8,960)TITLE2
      WRITE(8,962)BBTEMP
      WRITE(8,963)
      WRITE(8,964)
      WRITE(8,901)((P(I,J),J=1,5),I=1,NROWS)
      WRITE(8,999)WGTSUM,PLSUM

900   FORMAT(F7.0,F8.3,6F8.4,F10.4,3F8.4,F12.4)
901   FORMAT(2X,F7.0,2X,F6.3,4X,F6.4,10X,F9.7,11X,F6.3)
905   FORMAT(8I5, 2F10.3)
910   FORMAT(6I5, 4F10.3)
915   FORMAT(2F10.3, I10)
920   FORMAT(3F10.3)
925   FORMAT(I5, 18A4)
930   FORMAT(6F10.3, I5)
935   FORMAT(4I5)
940   FORMAT(8F10.3)
945   FORMAT(3F10.3)
950   FORMAT(I5)
955   FORMAT(2F8.4)
```

```
959   FORMAT(A43)
960   FORMAT(///A75)
961   FORMAT(///A75//)
962   FORMAT(15X,'(TEMP =',F6.0,' K)'//)
963   FORMAT(4X,'FREQ',3X,'WAVELGTH',2X,'WEIGHTED',5X,'PLANCKIAN
     +   FRACTION',4X,'NORMALIZED')
964   FORMAT(4X,'CM-1',3X,'MICRONS',4X,'TRANS',9X,'IN EACH GROUP',
     +   7X,'VARIABLE,U'/)
970   FORMAT(2X,'FREQ',2X,'WAVELGTH',2X,'TOTAL',4X,'H2O',5X,'CO2+',3X,
     +  'OZONE',2X,'N2 CONT',1X,'H2O CONT',1X,'MOL SCAL',1X,'AEROSOL',
     +  2X,'HNO3',3X,'AEROSOL',2X,'INTEGRATED')
971   FORMAT(2X,'CM-1',3X,'MICRONS',2X,'TRANS',4X,'TRANS',3X,'TRANS',
     +  2X,'TRANS',3X,'TRANS',3X,'TRANS',4X,'TRANS',4X,'TRANS',3X,
     +  'TRANS',2X,'ABSORB',3X,'ABSORBTION'/)
980   FORMAT(A18,F7.3,' KM')
981   FORMAT(A18,F7.3,' KM'////)
985   FORMAT(A18,F7.3,' DEG')
990   FORMAT(A18,A27,F5.1,' KM')
992   FORMAT('PATH TYPE      =    ',A10)
995   FORMAT(///'* * * *  PARAMETERS FOR THIS RUN  * * * *'/)
998   FORMAT(/7X,'AVG TRANS= ',F5.4)
999   FORMAT(/17X,'TAU=',F6.4,6X,'SUM=',F9.7)
1000  FORMAT(A18,1X,I6)

      END

C **********************  END OF MAIN PROGRAM  ********************** C

      SUBROUTINE PLFRAC(U1,U2,FRAC)

C-------------------------------------------------------------------C
C      THIS SUBROUTINE COMPUTES THE PLANCKIAN-FRACTIONAL-AREA       C
C      (FRAC) BETWEEN THE NORMALIZED VARIABLES U1 AND U2.           C
C-------------------------------------------------------------------C

      REAL PI,TEST,A1,A2,FRAC,SUM,U1,U2,U,DU,UEVAL,AREA
      REAL Y(1000), F(1000)

      INTEGER I,COUNT,N

      PI=2.0*ASIN(1.0)
      N=1000
      COUNT=0

600   COUNT=COUNT+1
      SUM=0.
      IF (COUNT .EQ. 1) THEN
         UEVAL=U2
        ELSE
         UEVAL=U1
        ENDIF
```

```
      DU=UEVAL/N

      DO 610 I=1,N
         U=I*DU
         Y(I)=(15/PI**4)*(U**3/(EXP(U)-1))
         IF (I .EQ. N) THEN
            GO TO 620
           ENDIF
         TEST=INT(I/2.)-(I/2.)
         IF (TEST .EQ. 0) THEN
            F(I)=2*Y(I)
            GO TO 630
           ELSE
            F(I)=4*Y(I)
            GO TO 630
           ENDIF
620   F(I)=Y(I)
630   SUM=SUM+F(I)
610   CONTINUE

      AREA=(DU/3.)*SUM
      IF (COUNT .EQ. 1) THEN
         A2=AREA
        ELSE
         A1=AREA
        ENDIF

      IF (COUNT .LT. 2) THEN
         GO TO 600
        ENDIF

      FRAC=ABS(A2-A1)

      END
```

VITA

Captain James M. Leonard was born on 21 August 1952 in St. Paul, Minnesota. He graduated from high school in Barre, Vermont in 1970 and attended the United States Air Force Academy from which he received the degree of Bachelor of Science in Engineering Sciences in June 1974. He completed Undergraduate Navigator Training and received his wings in April 1975. He then served as a C-141A navigator in the 86th Military Airlift Squadron at Travis AFB, California. In 1979 he was assigned as an instructor navigator in the Undergraduate Navigator Training program, with the 323rd Flying Training Wing at Mather AFB, California. He was awarded a Master of Science degree in System's Management, from the University of Southern California in 1982. He entered the School of Engineering, Air Force Institute of Technology, in August 1983.

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GNE/ENP/85M-13	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Engineering 6b. OFFICE SYMBOL (If applicable) AFIT/ENP	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, OH 45433	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19	

12. PERSONAL AUTHOR(S)
James M. Leonard, M.S.S.M., Captain, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1985 March	65

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Transmittance Thermal radiation Transmissivity Atmospheric optics
18	03		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: NUCLEAR THERMAL TRANSMITTANCE IN THE ATMOSPHERE USING LOWTRAN6 COMPUTER CODE

Lynn Wolaver 17 April 85

Thesis Chairman: Charles J. Bridgman, Phd.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Charles J. Bridgman, Phd.	22b. TELEPHONE NUMBER (Include Area Code) (513) 255-4498 22c. OFFICE SYMBOL AFIT/ENP

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

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SECURITY CLASSIFICATION OF THIS PAGE

A series of transmittance calculations using LOWTRAN6 were accomplished to provide the nuclear survivability analyst readily-accessible, accurate information when computing the effects of atmospheric nuclear radiation on selected systems.

Transmittance values for several realistic sets of atmospheric conditions were obtained using the 1962 U.S. Standard Atmospheric Model and the LOWTRAN Rural, Urban, Maritime, Tropospheric, and Stratospheric aerosol models. Boundary layer (0-2 km) transmittance calculations using the Rural, Urban, and Maritime aerosols, were accomplished for sea-level visibilities of 5, 10, 15, and 23 km. A computer program was developed to weight the LOWTRAN6 output transmittances according to a 6000 K Planckian distribution, thus simulating a nuclear weapon source. The geometry chosen is for the region where thermal radiation has a significant damage potential to Air Force systems; altitudes from sea-level to 20 kilometers, and ground ranges from 0-25 kilometers from weapon ground-zero. The results are displayed in a graphical format, providing the user with accurate nuclear thermal atmospheric transmittance data.

END

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